

Analysis of switching and matching stubs in reconfigurable power divider with SPDT switch function

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Abstract

In this paper, performance analysis of switching and matching stubs was done to a reconfigurable power divider with Single Pole Double Throw (SPDT) switch function. Two designs (Design A and Design B) with different positions of switches and matching stubs were proposed. Rogers RO4350 ($\epsilon_r=3.48$, $h=0.508$ mm) was used in this analysis as a substrate material with copper thickness of 0.035 mm. The performance analysis was carried out based on insertion loss, return loss and isolation parameters. The simulated results showed that Design B had a better performance than Design A and was able to work as a reconfigurable power divider with SPDT switch function.

Keywords: matching stubs, power divider, SPDT switch, switchable function, switching

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1. Introduction

Nowadays, reconfigurable mobile terminals have become a trend; thus, many reconfigurable antennas have been examined and demonstrated in practice to fulfill these targets [1-3]. Advanced feeding network is important to support systems such as the phase-array antennas and smart antennas in order for them to be fully functionable [4-6]. Wilkinson power divider (WPD) is one of the important components in numerous microwave circuits. It has been generally used to combine and split the power in antenna feeding networks [6-8]. The conventional WPD utilizes two quarter wavelength transmission lines and only operates at a certain frequency [9]. In [10], a power divider, which integrated coupler and filter, was designed for radar systems. However, it was not tunable and the design was very complex. Varactors can be utilized to achieve the tunable function of power dividers [11-17]. Nevertheless, the design of the power divider would become more complex when varactors are utilized in the design. In [18], a proposed tunable power divider was designed by electrifying the upper and lower surface electrodes of the liquid crystal and varying the voltage value. However, the design would make the fabrication process more difficult. Furthermore, tunable capabilities can also be obtained by utilizing PIN diodes in the design [19, 20]. SPDT switch function can also be achieved by using PIN diodes. PIN diodes are essential components in designing SPDT switch. In [21], the function of the power divider can be switchable, which means it can function as a power divider or SPDT switch by using PIN diodes in a single design. However, the size of the proposed design was too large and it was difficult to fabricate.

Therefore, this project presented two designs of miniaturized reconfigurable power divider with SPDT switch function for WiMAX standards, at 2.5 GHz and 3.5 GHz, with different positions of switches and matching stubs. The proposed power dividers comprised of two modified WPDs which can be reconfigured in length by using PIN diode switches. By varying the bias voltage of the PIN diodes, the operating frequency can be altered, either at 2.5 GHz or 3.5 GHz. Furthermore, the proposed designs also had a switchable function; either as a power divider or SPDT switch as compared to [19]. Figure 1 shows the circuit configurations of power divider with SPDT switch function in Design A and Design B. The proposed designs had a new feature which was a multiband for both functions compared to [21]. However, there was a mismatch when the function was switched to SPDT switch. Therefore, two shorted stubs were introduced at the output ports for matching SPDT switch at 2.5 GHz and 3.5 GHz. In this paper, two proposed designs of reconfigurable power divider with SPDT switch function were simulated

and investigated. Figure 1 shows the circuit configurations of power divider with SPDT switch function in Design A and Design B.

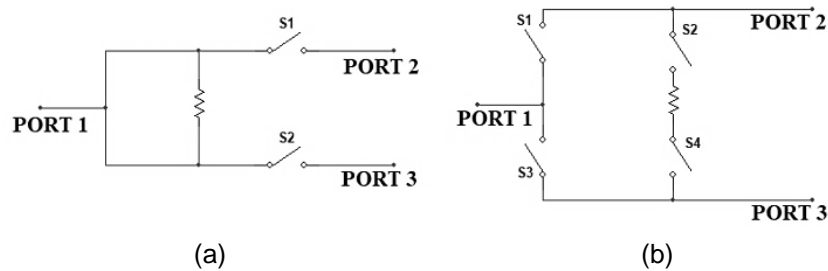


Figure 1. The circuit configurations of power divider with SPDT switch function in (a) design A and (b) design B.

Furthermore, the proposed designs had a new feature which is multiband for both functions compared to [21]. However, there was mismatch when the function is switched into SPDT switch. Therefore, two shorted stubs were introduced at the output ports for matching the 2.5 GHz and 3.5 GHz SPDT switch. In this paper, two proposed designs of reconfigurable power divider with SPDT switch function were designed, simulated and investigated.

2. Research Method

2.1. Wilkinson Power Divider and Design Equation

In 1960, Ernest Wilkinson proposed the Wilkinson power divider (WPD), which gives isolation between ports at the output, and is adept to match in all ports. It can also be lossless when the port at the output is matched [22]. Figure 2 shows the equal transmission line circuit for WPD that delivers an equal force to both ports at the output [9].

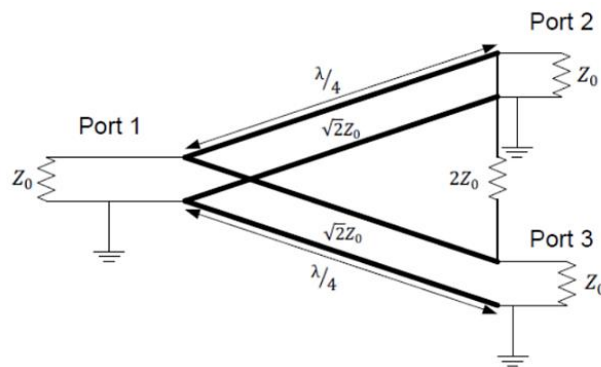


Figure 2. The circuit model of transmission line for WPD [9]

WPD is a three-port network that consists of one input port and two output ports as shown in Figure 2. Generally, the power can be divided equally or unequally at two different working frequencies depending on the application. Based on the conventional WPD, two WPDs were designed for working frequencies of 2.5 GHz and 3.5 GHz. Z_0 value of $50\ \Omega$ was used in the design. Furthermore, the design also included an isolation resistor of isolation resistor with a value of $2Z_0=100\ \Omega$ and an impedance of a quarter-wave section split transmission line with a value of $\sqrt{2}Z_0=70.7\ \Omega$. In (1) shows a perfect scattering matrix (S-matrix) of WPD with a load. The S-matrix shows that when a signal enters Port 2, it will be the same as Port 3, as it is

separated equally into Port 2 and Port 3. Ports that are matched sets (S11, S22 and S33) are equal to zero. The power divider is lossless as the signal enters Port 1. The magnitude, which is the total squares of each component, of column one of the S-matrix, is equivalent to one [9].

$$S = \frac{-j}{\sqrt{2}} \begin{pmatrix} 0 & 1 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix} \quad (1)$$

2.2. Proposed Design for Modified WPD and SPDT Switch

Figure 3 (a) and Figure 3 (b) show the two proposed designs of the reconfigurable power divider with SPDT switch function; Design A and Design B, with different positions of switches and matching stubs in the designs. In the proposed designs, PIN diodes play an important role to achieve dual functions, either as a reconfigurable power divider or SPDT switch, and also multiband in a single design.

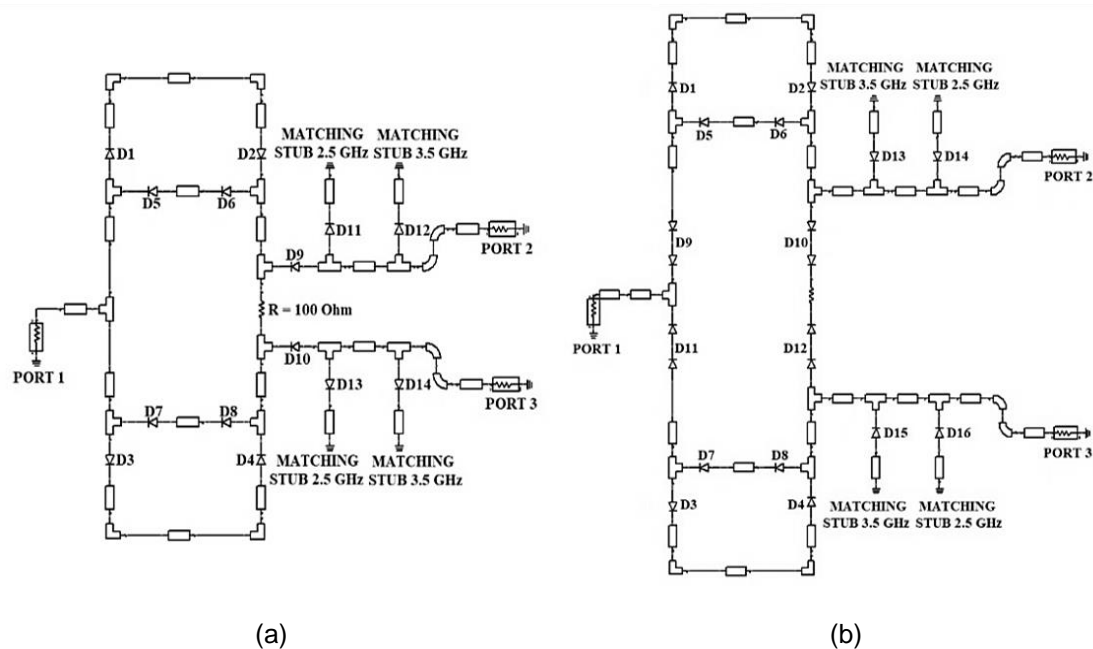


Figure 3. (a) Design A and (b) Design B is the proposed designs for switchable function of reconfigurable power divider and SPDT switch

From Figure 3, it can be seen that Design A and Design B have different positions of switches and matching stubs. In Figure 2 (a), when D5, D6, D7, D8, D11, D12, D13 and D14 are turned off, the circuit operates as a power divider at a frequency of 2.5 GHz and when D1, D2, D3, D4, D11, D12, D13 and D14 are turned off, the power divider operates at a frequency of 3.5 GHz. Meanwhile, for Figure 3 (b), when D5, D6, D7, D8, D13, D14, D15 and D16 are turned off, the power divider operates at 2.5 GHz. When D1, D2, D3, D4, D13, D14, D15 and D16 are turned off, the power divider operates at 3.5 GHz. Figure 4 (a) and Figure 4 (b) show the circuit configurations when the circuit operates as a power divider at 2.5 GHz and 3.5 GHz, respectively.

From Figure 3 (a), in order to turn off one of the connected output ports for SPDT switch function, PIN diode D9 or D10 are turned off. Meanwhile, for Figure 3 (b), when D10, D11 and D12 are turned off, Port 3 will achieve the SPDT switch function. Whereas, when D9, D10 and D12 are turned off, Port 2 will be disconnected. However, there will be a mismatch when one of the output ports is turned off. This can be overcome by placing the stubs at the output port. Hence, two stubs were placed at the output port for matching SPDT switch at 2.5 GHz and

3.5 GHz. The SPDT switch function was also reconfigurable in terms of its operating frequency. It can operate either at 2.5 GHz or 3.5 GHz. Figure 5 (a) and Figure 5 (b) show the circuit configuration for SPDT switch function at 2.5 GHz and 3.5 GHz, respectively.

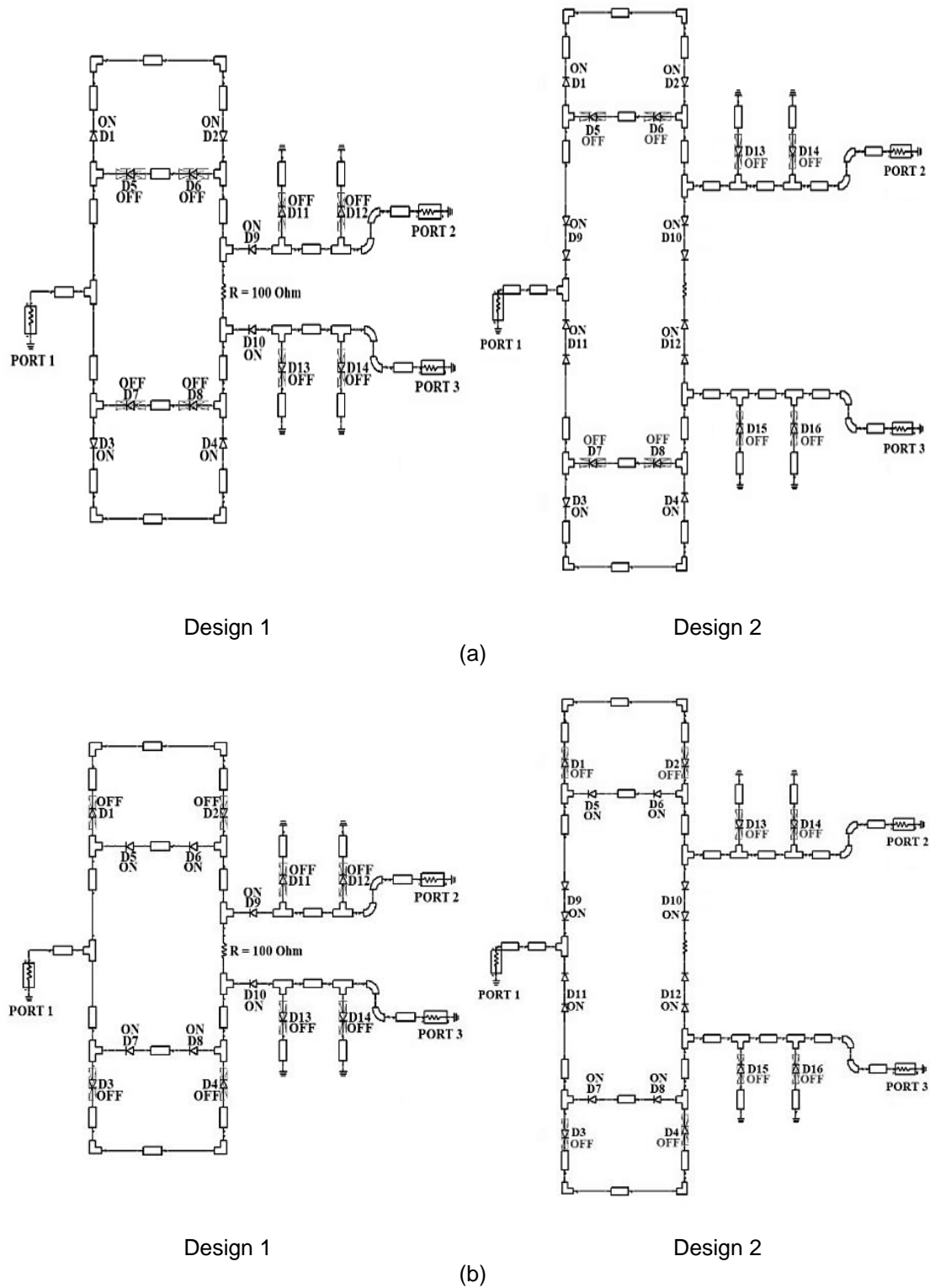
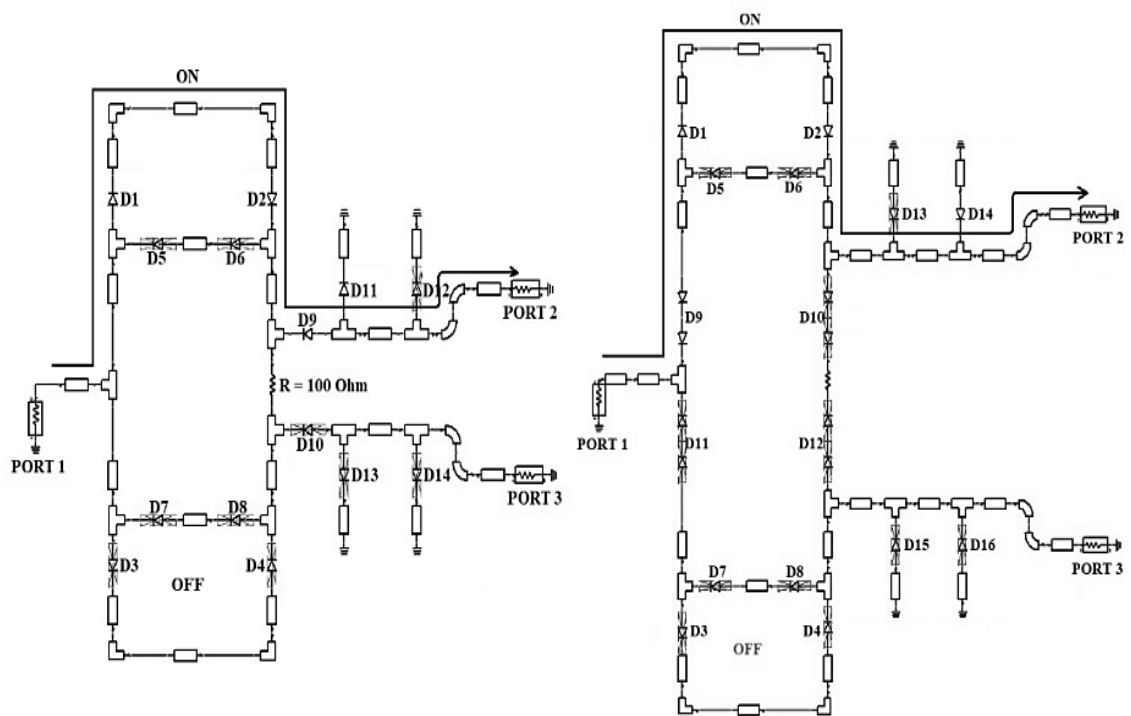


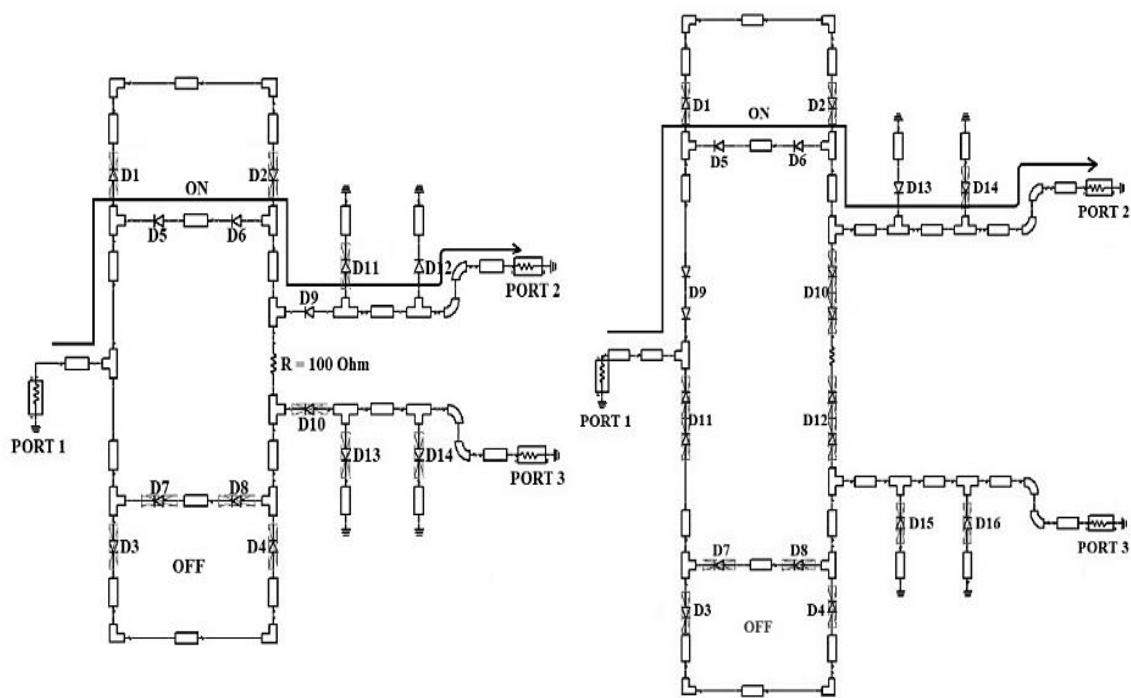
Figure 4. (a) Circuit configuration of power divider at 2.5 GHz and (b) circuit configuration of power divider at 3.5 GHz



Design 1

Design 2

(a)



Design 1

Design 2

(b)

Figure 5. (a) The circuit configuration for SPDT switch at 2.5 GHz and
(b) the circuit configuration for SPDT switch at 3.5 GHz

3. Results and Analysis

3.1. The Proposed Designs of Reconfigurable Power Divider

In the proposed designs, two modified WPD designs were combined. By using PIN diode, it reconfigured the length of the transmission line of the power divider. From Figure 3, PIN diodes D1 to D8 controlled the operating frequency of the proposed designs. The proposed power divider in Figure 4 was simulated to obtain the S_{11} , S_{12} , S_{13} , S_{21} , S_{31} and S_{23} at 2.5 GHz and 3.5 GHz. Figure 6 and Figure 7 show the results for S_{11} , S_{12} , S_{13} and S_{23} at 2.5 GHz and 3.5 GHz, respectively. For the power divider of Design A, PIN diodes D11 to D14 were turned off. Meanwhile, for Design B, D13 to D16 were turned off. The PIN diodes were connected to the matching stubs. These matching stubs only turned on for the SPDT switch function.

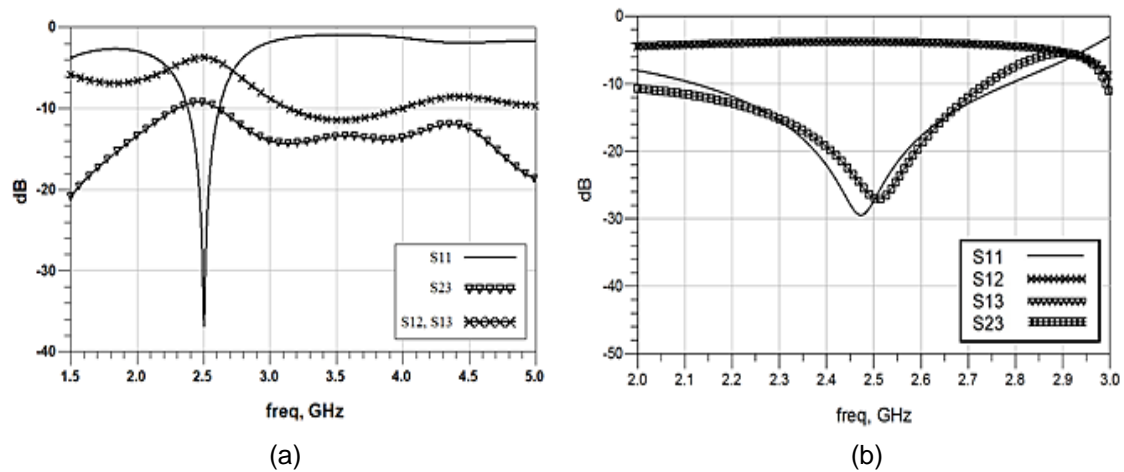


Figure 6. S_{11} , S_{12} , S_{13} , S_{21} , S_{31} and S_{23} results for modified WPD
(a) design A and (b) design B at 2.5 GHz.

From Figure 6 and Figure 7, the results of the S-parameters for Design B had better performances than Design A. The isolation for Design A was not ideal in Figure 6 (a), as the isolation must be less than -10 dB.

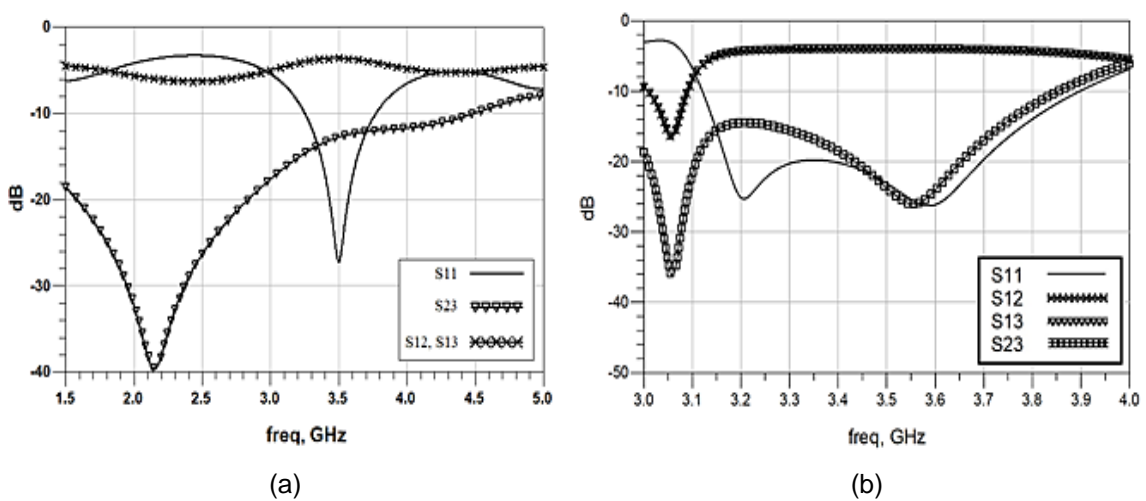


Figure 7. S_{11} , S_{12} , S_{13} , S_{21} , S_{31} and S_{23} results for modified WPD
(a) design A and (b) design B at 3.5 GHz.

3.2. Design of Reconfigurable SPDT Switch

In Design A, PIN diodes D9 and D10 played an important role to switch from reconfigurable power divider to SPDT switch. When one of the PIN diodes (D9 or D10) is turned off, the proposed design will act as a SPDT switch. It can switch either using Port 2 or Port 3. In addition, the SPDT switch was also reconfigurable in terms of its operating frequency. It can operate at 2.5 GHz or 3.5 GHz. However, when one of the ports is turned off, there will be a mismatch. Therefore, in the proposed designs, two stubs were added to overcome this problem. One stub for matching the SPDT switch at 2.5 GHz and the other at 3.5 GHz. These stubs will be turned on when needed. For example, in Design A, when Port 2 is needed to be turned on, PIN diode D9 will be turned on and D10 will be turned off. For the matching stubs, D11 will be turned on for the SPDT switch function at 2.5 GHz.

Meanwhile, in Design B, the position of the switch was different from Design A. The PIN diodes, which controlled the switchable function, were D9 to D12. These PIN diodes controlled the connection of the output ports; Port 2 and Port 3. The matching stubs were connected to PIN diodes D13 to D16. The position of the matching stubs in Design B was also different compared to Design A as shown in Figure 3.

Figure 8 and Figure 9 show the return loss, S11, insertion loss, S12, S13 and isolation, S23 at 2.5 GHz and 3.5 GHz for SPDT switch, respectively. It can be seen that both frequencies have return loss of less than -15 dB, insertion loss less than -2 dB and isolation less than -20 dB. From Figure 8 (a) and Figure 9 (a), Design A has infinity isolation because the design is still in ideal form, whereas for Design B, the isolation is below -30 dB.

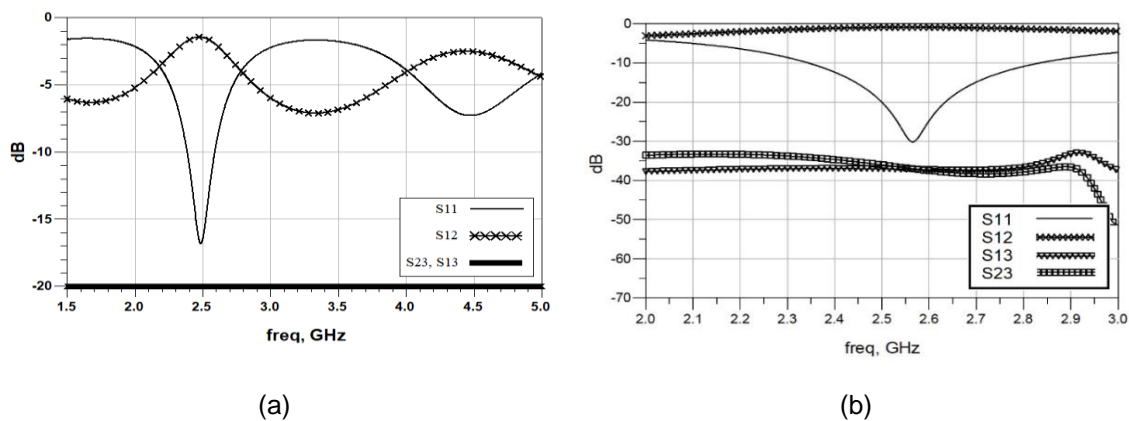


Figure 8. Simulation result, S11, S12, S13, S21, S31 and S23 for SPDT switch (a) design A and (b) design B at 2.5 GHz.

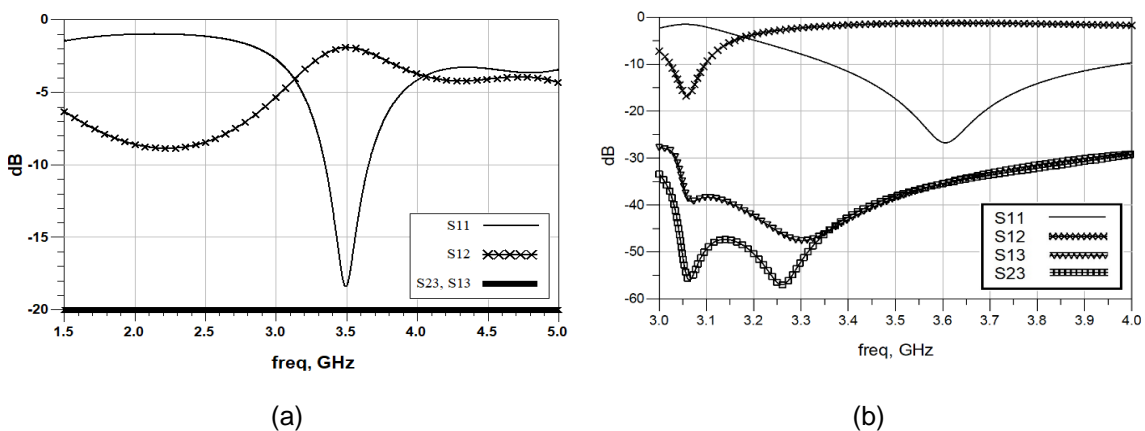


Figure 9. Simulation result, S11, S12, S13, S21, S31 and S23 for SPDT switch (a) design A and (b) design B at 3.5 GHz.

Parametric study was done on Design A to improve its performance for both functions at 2.5 GHz and 3.5 GHz. However, it cannot be further improved for both functions. It cannot achieve good performance, as expected. Meanwhile, for Design B, after the position of the switches and matching stubs was changed, the design managed to achieve the expected outcome for both functions either at 2.5 GHz or 3.5 GHz. Table 1 shows the comparison of the proposed designs, Design A and Design B, in terms of performances. Design B had a better performance than Design A for both functions at different operating frequencies.

Table 1. Comparison of the Performances for Design A and Design B

		Power Divider		SPDT Switch	
		2.5 GHz	3.5 GHz	2.5 GHz	3.5 GHz
Design A	Center frequency, f_o	2.5 GHz	3.5 GHz	2.5 GHz	3.5 GHz
	Return loss	34.732 dB	27.252 dB	16.510 dB	18.354 dB
	Insertion loss	3.733 dB	3.634 dB	1.482 dB	1.922 dB
	Isolation	> -10 dB	< -10 dB	∞	∞
Design B	Return loss	27.338 dB	23.090 dB	20.064 dB	17.395 dB
	Insertion loss	3.815 dB	3.990 dB	0.929 dB	1.351 dB
	Isolation	-26.954 dB	-23.729 dB	-37.045 dB,	-38.542 dB,
				-36.026 dB	-38.122 dB

4. Conclusion

Two proposed designs of the reconfigurable power divider with SPDT switch function with different positions of switches and matching stubs were successfully designed, simulated, and investigated. The simulation results for power divider of Design B were good at both frequencies with return loss of below -20 dB, S12/S13 better than -3.990 dB and isolation less than -20 dB. Meanwhile, for the SPDT function of Design B, the simulation results were also good at both frequencies with return loss of less than -15 dB, insertion loss better than -2 dB and isolation less than -30 dB.

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